Department of Foundations of Computer Science

The research performed in the Department of Foundations of Computer Science lies in the intersection of algebra, logic and computer science. The main studied themes are automata and formal languages, lexicographic orderings of languages, context-free languages of infinite words, tree automata, tree transducers and term rewriting, semirings, semimodules, weighted automata and weighted tree automata, logics on words and trees, finite model theory, fixed point operations in computer science, and axiomatic questions.

I. ITERATION THEORIES AND FIXED POINT OPERATIONS

Most computer scientists are aware of the fact that just about all their work is related to fixed points and fixed point operations. Prior work by Bloom, Ésik and others led to the notion of 'iteration theories' that capture the equational properties of fixed point operations in computer science. Iteration theories were studied and applied to programming semantics, automata and language theory, concurrency in the papers [1–6].

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[2] S.L. Bloom and Z. Ésik, A Mezei-Wright theorem for categorical algebras, *Theoret. Comput. Sci.*, 411(2010) 341–359.

[3] Z. Ésik and T. Hajgató, Kleene theorem in partial Conway theories with applications, *Algebraic Foundations in Computer Science*, Essays dedicated to Symeon Bozapalidis on the occasion of his retirement, LNCS 7020, Springer, 2011, 72–93.

[4] Z. Ésik and T. Hajgató, Dagger extension theorem, *Math. Struc. in Comp. Sci.*, 21(2011), 1036–1066.

[5] Z. Ésik, Residuated Park theories, *J. Logic and Computation*, published online February 5, 2013.

[6] Z. Ésik, On a connection between language theory and concurrency, *Math. Found. Programming Semantics*, New Orleans, 2013, to appear.

II. SEMIRINGS, SEMIMODULES AND SEMIALGEBRAS

Semirings, semimodules and semialgebras have been widely used in computer science to describe the behavior of weighted automata. Many new types of these structures, such as (partial) Conway and iteration semirings and semialgebras, were used to provide an axiomatic framework to weighted automata in the papers [7–13]. For example, it has been shown that rational power series may be axiomatized by the equations of iteration semirings and a few more.

[7] S.L. Bloom, Z. Ésik and W. Kuich, Cycle-free finite automata in partial iterative semirings, *Int. Conf. Algebraic Informatics*, CAI 2009, Thessaloniki, LNCS 5725, Springer, 2009, 1–12.

[8] Z. Ésik and W. Kuich, Axiomatizing rational series, *8th Panhellenic Logic Symposium*, Ioannina, 2011, 30–34.

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III. AUTOMATA, TREE AUTOMATA, WEIGHTED AUTOMATA

Research on automata has been performed in several directions. In addition to classical finite automata, it included tree automata and weighted automata with respect to both the classical language behavior and the bisimulation based behavior, see [16, 21–23]. In [18–20], we used tree automata to characterize the expressive power of branching time temporal logics and first-order logic enriched with Lindström quantifiers. In [17], we gave a complete axiomatization of the algebra of regular tree languages.

In [33], we studied the nondeterministic variants of synchronizing automata.

In [25] we explore weighted extended tree transducers (wxtt) over countably complete semirings systematically. We show that the backward application of a linear wxtt preserves recognizability and that the domain of an arbitrary bottom-up wxtt is recognizable.

In [14] we characterize equational tree transformations in terms of tree transformations defined by different bimorphisms, and give an equational definition for some well-known tree transformation classes. In [15] we generalize these results for weighted tree transformations with finite support over continuous and commutative semirings, and in [26] for weighted tree transformations over the max-plus semiring.

In [31] we characterize the syntactic $K\Sigma$-algebras of recognizable tree series and show that all subdirectly irreducible $K\Sigma$-algebras are syntactic. In [27] we prove a variety theorem for tree series over a field K, which establishes a bijective correspondence between the varieties of recognizable $K\Sigma$-tree series and the varieties of certain finite-dimensional $K\Sigma$-algebras.

In [28] we show that both the forward and the backward application of synchronous tree substitution grammars (stsg) preserve recognizability of weighted tree languages in all reasonable cases. As a consequence, both the domain and the range of an stsg without chain rules are recognizable weighted tree languages.

In [30] we prove that a tree series is recognizable by a tree automaton over a multioperator monoid iff it appears as the composition of a relabeling tree transformation, a recognizable tree language, and a tree series computed by a one-state weighted tree automaton of the same type. In [32] we present a KLEENE theorem on the equivalence of recognizability and rationality for tree series over distributive multioperator monoids. In [24] we prove that a tree series over an absorptive multioperator monoid is recognizable by weighted tree automata iff it is definable by certain MSO-like expressions.

In [34] we introduced the concept of a tree homomorphism for unranked trees. We show that they preserve recognizability.

In [35] we compare the computing powers of a given deterministic bottom-up tree transducer and a given ground term rewrite system.

[14] S. Bozapalidis, Z. Fülöp and G. Rahonis, Equational tree transformations, *Theoret. Comput. Science*, 412(2011), 3676–3692.

[15] S. Bozapalidis, Z. Fülöp and G. Rahonis, Equational weighted tree transformations, *Acta Informatica*, 49 (2012), 29–52.

[16] Z. Ésik and A. Maletti, Simulation vs. equivalence, *Int. Conf. Foundations of Computer Science*, FCS 2010, Las Vegas, Nevada, CSREA Press, 2010, 119–122.

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[22] Z. Ésik and A. Maletti, The category of simulations for weighted tree automata, *Int. J. Foundations of Comp. Sci.*, 22(2011), 1845–1859.

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[25] Z. Fülöp, A. Maletti and H. Vogler, Weighted extended tree transducers, *Fundamenta Informaticae*, 111(2011), 163–202.

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[27] Z. Fülöp and M. Steinby, Varieties of recognizable tree series over fields, *Theoret. Comput. Science*, 412(2011), 736–752.

[28] Z. Fülöp, A. Maletti and H. Vogler, Preservation of recognizability for synchronous tree substitution grammars, *2010 Workshop on Applications of Tree Automata in Natural Language Processing*, (F. Drewes and M. Kuhlmann eds.) The Association for Computational Linguistics, 2010, 1–9.

[29] Z. Fülöp and L. Muzamel, Weighted tree-walking automata, *Acta Cybernetica*, 19(2009), 275–293.

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[34] X. Piao, K. Salomaa, S. Vágvölgyi, Tree homomorphisms for unranked trees, *Automata and Formal Languages*, AFL 2011, Debrecen, Novadat, 2011, 343-357.

[35] S. Vágvölgyi, Deterministic bottom-up tree transducers and ground term rewrite systems, *Theoretical Computer Science*, 410(2009), 2250–2278.

IV. LEXICOGRAPHIC ORDERINGS

Each countable linear ordering may be represented as the lexicographic ordering of a language over some alphabet. But which linear orderings may be represented as lexicographic orderings of regular or (deterministic) context-free languages? Is it decidable whether they are well-orderings, scattered orderings or dense orderings? These questions and many others were studied in the papers [36, 38, 39, 41, 43–45]. For example, we showed that the finite condensation rank of the lexicographic ordering of a context-free language is less than ω^ω, and that a well-ordering is the lexicographic ordering of a context-free language iff it is the lexicographic ordering of a deterministic context-free language iff its order type is less than ω^{ω^ω}. We also proved that there is a context-free language whose lexicographic ordering is not isomorphic to the lexicographic ordering of any deterministic context-free language. Moreover, whereas it is decidable for a context-free grammar whether the lexicographic ordering of its language is a well-ordering or a scattered ordering, it is undecidable whether it is dense. We also constructed a context-free language whose lexicographic ordering has an undecidable first-order theory. This is interesting since the the lexicographic ordering of any deterministic context-free language has a decidable first-order, even decidable monadic second-order theory.

[36] S.L. Bloom and Z. Ésik, Scattered algebraic linear orderings, *Fixed Points in Computer Science*, Coimbra, 2009, Edited by Ralph Matthes and Tarmo Uustalu, 25–29.

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V. LANGUAGES OF INFINITE WORDS

The theory of context-free languages of finite words may be extended to infinite words if one allows a derivation tree to be infinite and requires some (e.g. Büchi– or Muller–type) acceptance condition to hold over the branches of the tree. In [46, 47, 49, 51, 53] we considered the (closure, complexity, order-theoretic etc.) properties of the languages generated by context-free grammars equipped with a Büchi–type condition, while in [48,50,52] we studied the languages generated by grammars with a Muller–type condition.

[46] Z. Ésik and S. Iván, Context-free languages of countable words, *Int. Conf. Theoret. Aspect of Computing*, ICTAC 09, Kuala Lumpur, LNCS 5684, Springer, 2009, 185–199.

[47] Z. Ésik, W. Kuich and M. Ito, Linear languages of finite and infinite words, *Automata, Formal Languages, and Algebraic Systems*, World Scientific, 2010, 33–46.

[48] Z. Ésik and S. Iván, On Muller context-free grammars, in Proc. *Developments in Language Theory*, London, ON, 2010, LNCS, Volume 6224, Springer, 173-184, 2010.

[49] Z. Ésik and S. Iván, Büchi context-free languages, *Theoretical Computer Science*, 412(2011), 805–821.

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[51] Z. Ésik and S. Okawa, On context-free languages of scattered words, *DLT 2012*, Taipei, LNCS 7410 Springer, 2012, 142–153.

[52] Z. Ésik and S. Iván, Operational characterization of scattered MCFLs, *Developments in Language Theory*, DLT 2013, Paris, LNCS 7907, Springer, 2013, 215–226.

[53] S. Iván and Á. Mészáros, Muller context-free grammars generating well-ordered words, *AFL2011*, Debrecen, 2011, 225–240.

VI. TERM REWRITE SYSTEMS

In [54] we showed that it is decidable for any extended ground term rewrite system R whether there is an equivalent ground term rewrite system S.

In [55], we show that for any equivalent reduced ground term rewrite systems R and S, the same number of terms appear as subterms in R as in S. We give an upper bound on the number of reduced ground term rewrite systems equivalent to a given reduced ground term rewrite system R.

In [56] we presented a new variant of the PPP Challenge Handshake Authentication Protocol. We based our version on the concept of rewrite complements for ground term rewrite systems.

[54] S. Vágvölgyi, Congruences generated by extended ground term rewrite systems, *Fundamenta Informaticae*, 95(2009), 381–399.

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VII. MISCELLANEOUS

[57] Z. Ésik, Y. Gao, G. Liu and S. Yu, Estimation of state complexity of combined operations, *Theoret. Comput. Sci.*, 410(2009), 3272–3281.

[58] L. Aceto, A. Carayol, Z. Ésik and A. Ingólfsdóttir, Algebraic synchronization trees and processes, *ICALP 2012*, Warwick, 2012, Proceedings, Part II. Lecture Notes in Computer Science 7392, Springer 2012, 30–41.

VIII. SURVEY PAPERS, BOOK CHAPTERS

[59] Z. Ésik, Fixed point theory, in: *Handbook of Weighted Automata*, Springer, 2009, 29–65.

[60] Z. Ésik and W. Kuich, Finite automata, in: *Handbook of Weighted Automata*, Springer, 2009, 69–104.

[61] S. Aleshnikov, J. Boltnev, Z. Ésik, S. Ishanov and W. Kuich, Formal languages and automata V: Conway semiring-semimodule pairs and finite automata, *Westnik Rossijskogo Gosudarstvennogo Universiteta im. I. Kanta. Wyp. 10. Ser. Fiziko-matematitscheskije nauki*, 2009, 6–41. (Russian)

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IX. EDITED VOLUMES

[65] P. Dömösi and Sz. Iván, Eds., Proc. *Automata and Formal Languages*, Debrecen, 2011.

[66] Z. Ésik and Z. Fülöp, Eds., *Automata, Formal Languages, and Related Topics*, Dedicated to Ferenc Gécseg on the occasion of his 70th birthday, University of Szeged, 2009.

[67] E. Csuhaj-Varjú and Z. Ésik, Eds., *Automata and Formal Languages*, Acta Cybernetica, Vol. 19, No. 2, 441–565, 2009.

[68] E. Csuhaj-Varjú and Z. Ésik, Eds., *Automata and Formal Languages*, special issue devoted to AFL 2008, Int. J. Foundations of Computer Science, Volume 21, Number 5, October 2010.

[69] P. Dömösi and Z. Ésik, Eds., *Automata and Formal Languages*, spec. issue devoted to the 2011 AFL conference, Int. J. Foundations of Computer Science, Vol. 23, No. 6, 2012.

[70] Z. Ésik and D. Miller, *Fixed Points in Computer Science* 2012, EPTCS, Vol. 77, 2012.

X. OTHER ACTIVITIES

Zoltán Fülöp was a member of the PC of the conferences Automata and Formal Languages 2011 (Debrecen) and Algebraic Informatics (Linz) 2011. He is a member of the Editorial Board of Acta Cybernetica.

Zoltán Ésik was a member of the PC of the conferences Algebraic Informatics (Porquerolles Island) France, 2013, Developments in Language Theory (Paris) 2013, Mathematical Foundations of Computer Science (Vienna) 2013, Descriptional Complexity of Formal Systems (Braga) 2012, Fixed Points in Computer Science (Tallinn) 2012 (co-chair), Foundations of Software Technology and Theoretical Computer Science (Mumbai) 2011, Descriptional Complexity of Formal Systems (Giessen) 2011, Developments in Language Theory (Milan) 2011, International Colloquium on Automata, Languages and Programming (Zurich) 2011, Automata and Formal Languages (Debrecen) 2011, Fixed Points in Computer Science (Brno) 2010, Foundations of Software Technology and Theoretical Computer Science (Chennai) 2010, Fixed Points in Computer Science (Coimbra) 2009, Mathematical and Engineering Methods in Computer Science (Brno) 2009, Developments in Language Theory (Stuttgart) 2009, Quantitative Logics (Rhodes) 2009 (chair), Symposium on Theoretical Aspects of Computer Science (Freiburg) 2009.

He was an invited speaker of the conferences Workshop on Lattices and Relations (Amsterdam) 2012, Weighted Automata: Theory and Applications (Dresden) 2012, Algebras, Languages, Algorithms and Computation (Kyoto) 2011, Highlights of Automata (Vienna) 2010, Weighted Automata: Theory and Applications (Leipzig) 2010, AUTOMATHA 09 (Liege) 2009. Zoltán Ésik served on the steering committees od the conference series Fundamentals of Comutation Theory, Algebraic Informatics, Fixed Points in Computer Science, Automata and Formal Languages.

He is a member of the Editorial Board of Theoretical Computer Science, Theoretical Informatics and Applications, Algebra (Hindawi Publishing Corporation), Acta Cybernetica, and Alkalmazott Matematikai Lapok (J. Applied Mathematics, János Bolyai Math. Soc.).

Zoltán Ésik has been a member of the council of the European Association of Computer Science (EATCS) and the Committee for Theoretical Computer Science of the International Federation for Information Processing (IFIP). Until 2010, he was also a member of the board of the European Association for Computer Science Logic (EACSL).

XI. AWARDS

In 2010, Szabolcs Iván was awarded Gyula Farkas Prize (János Bolyai Math. Soc.). Zoltán Ésik was elected member of the Academy of Europe in 2010.

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